

## SILICON-ON-INSULATOR DEVICE STRUCTURE

### DESCRIPTION

#### CROSS-REFERENCE TO RELATED APPLICATION

[Para 1] This application is a divisional of a prior application serial no. 10/248,868, filed February 26, 2003.

#### BACKGROUND OF THE INVENTION

[Para 2] Field of Invention

[Para 3] The present invention relates to a semiconductor device. More particularly, the present invention relates to a silicon-on-insulator (SOI) device structure.

[Para 4] Description of Related Art

[Para 5] Silicon-on-insulator (SOI) structure is a common substrate for building semiconductor devices. In a SOI structure, an insulation layer (mostly silicon dioxide) is formed not far away from the surface of a silicon substrate. The insulation layer isolates a silicon layer used for building semiconductor devices from the silicon substrate and hence the name silicon-on-insulator. Because the semiconductor devices is formed in a layer separated from the silicon substrate by the insulation layer, some latch-up pathways of transistors in the active area such as the ones between a source terminal and the substrate or a well region and the substrate no longer exists.

[Para 6] Aside from the elimination of pre-existing junction parasitic capacitance in the devices on the bulk silicon wafer and effectively limiting latch-up in semiconductor devices due to parasitic bipolar effect,

semiconductor devices on a SOI structure also has a greater immunity against soft errors caused by the bombardment of alpha particles.

[Para 7] A device fabricated on a conventional SOI substrate has two major characteristics, the floating-body effect and body-tied characteristic. The floating-body effect increases the opening current when a device is switched on. However, the floating-body effect also increases the terminating current when the device is shut down. Ultimately, performance and reliability of the device are affected. Thus, the so-called body-tied characteristic is often employed to facilitate the electrical coupling between the source terminal of the device with the main silicon body so that the shut down current is properly controlled. Yet, the body-tied characteristic tends to limit the floating-body effect of the SOI device. Therefore, the floating-body effect and the body-tied characteristic antagonize each other and render their concurrent usage self-defeating.

## SUMMARY OF THE INVENTION

[Para 8] Accordingly, one object of the present invention is to provide a silicon-on-insulator device structure that encompasses the advantages of floating-body effect and body-tied characteristic so that the device can have a higher opening current and a controlled current when the device is shut down. Hence, reliability of the device is improved without compromising device performance.

[Para 9] To achieve these and other advantages and in accordance with the purpose of the invention, as embodied and broadly described herein, the invention provides a silicon-on-insulator (SOI) device structure. The structure includes a silicon-on-insulator substrate, a first transistor and a second transistor. The first transistor and the second transistor are disposed on the silicon-on-insulator substrate such that the two transistors use a common source region. Furthermore, the drain terminal of the second transistor is electrically connected to the main body of the first transistor.

[Para 10] In this invention, a second transistor (a control transistor) is disposed between the source terminal of a first transistor (the silicon-on-insulator device) and a silicon main body. With this circuit configuration, the

second transistor (the control transistor) can be turned on or off according to actual requirement. Hence, the advantages of both floating-body effect and body-tied characteristic can be combined to improve device reliability and maintain performance level.

[Para 11] This invention also provides an alternative silicon-on-insulator (SOI) device structure. The structure includes a silicon-on-insulator substrate, a first gate structure and a second gate structure, a source region, a first drain region, a second drain region, a doped region and a conductive line. The first gate structure and the second gate structure is disposed on the silicon-on-insulator substrate. The source region is formed in the silicon-on-insulator substrate between the first gate structure and the second gate structure. The first drain region is formed in the silicon-on-insulator substrate on one side of the first gate structure and the second drain region is formed in the silicon-on-insulator substrate on the other side of the second gate structure. The doped region is formed in the silicon-on-insulator to connect electrically with the silicon-on-insulator substrate underneath the first gate structure. The conductive line is formed over the silicon-on-insulator substrate to connect the doped region and the second drain region electrically.

[Para 12] The doping type of the doped region is identical to that of the silicon-on-insulator substrate and the doping type of the first drain region, the source region and the second drain region is opposite to the silicon-on-insulator substrate. The conductive line connects the second drain region and the doped region through a first contact and a second contact. In other words, the conductive line connects the second drain region with the silicon-on-insulator substrate underneath the first gate structure.

[Para 13] According to the aforementioned embodiment, a first gate structure and a second gate structure are formed over a silicon-on-insulator substrate with the second gate structure serving as a control gate. Thereafter, the source terminal of the first gate structure is connected to the second gate structure. Through the second drain region, the first contact, the conductive line, the second contact and the doped region, the first gate structure is electrically connected to the silicon-on-insulator substrate (main body)

underneath the first gate structure. With this circuit configuration, the second gate structure (the control gate) can be turned on or off according to actual requirement. Hence, the silicon-on-insulator device may combine the advantages of both floating-body effect and body-tied characteristic to improve device reliability without compromising the performance level.

[Para 14] This invention also provides a method of operating a silicon-on-insulator device. The silicon-on-insulator device includes a transistor and a control transistor. The transistor and the control transistor share a common source terminal. The drain terminal of the control transistor is electrically connected to the main body of the transistor. To turn the transistor on, a bias voltage  $V_{cc}$  is applied to the drain terminal of the transistor, a bias voltage  $V_{cc}$  is applied to the gate terminal of the transistor and 0V is applied to the gate terminal of the control gate. Thus, the main body of the transistor is electrically disconnected from the source terminal of the transistor so that the transistor has a characteristic of floating-body silicon-on-insulator device. Conversely, to turn the transistor off, a bias voltage  $V_{cc}$  is applied to the drain terminal of the transistor so that the gate terminal and the source terminal of the transistor are at 0V. In the meantime, a bias voltage  $V_{cc}$  is applied to the gate terminal of the control transistor so that the main body and the source terminal of the transistor are electrically connected. Hence, the transistor has a characteristic of non-floating body silicon-on-insulator device.

[Para 15] A control transistor is disposed between the source terminal of a silicon-on-insulator device and a silicon main body in this invention. To switch on the silicon-on-insulator device, the control transistor is shut down. Since the main body of the silicon-on-insulator device is disconnected from the source terminal electrically, the silicon-on-insulator device has a characteristic of floating-body silicon-on-insulator device. Therefore, a higher opening current is obtained. To switch off the silicon-on-insulator device, the control transistor is turned on so that the main body of the silicon-on-insulator device connects electrically with the source terminal and the silicon-on-insulator device has a characteristic of non-floating body silicon-on-insulator device. Thus, a lower shutdown current is obtained. In this

invention, a control transistor is disposed between the source terminal of a silicon-on-insulator device and a silicon main body such that the control transistor is permitted to switch on or off on demand. Hence, the silicon-on-insulator device is able to embody the advantages of both the floating-body effect and body-tied characteristic and improve the reliability without compromising overall performance level.

[Para 16] It is to be understood that both the foregoing general description and the following detailed description are exemplary, and are intended to provide further explanation of the invention as claimed.

#### BRIEF DESCRIPTION OF THE DRAWINGS

[Para 17] The accompanying drawings are included to provide a further understanding of the invention, and are incorporated in and constitute a part of this specification. The drawings illustrate embodiments of the invention and, together with the description, serve to explain the principles of the invention. In the drawings,

[Para 18] Fig. 1 is a circuit diagram of a silicon-on-insulator device according to one preferred embodiment of this invention;

[Para 19] Fig. 2 is a top view of a silicon-on-insulator device according to one preferred embodiment of this invention;

[Para 20] Figs. 3A to 3E are schematic top views showing the steps for producing a silicon-on-insulator device according to one preferred embodiment of this invention; and

[Para 21] Figs. 4A to 4E are schematic cross-sectional views showing the steps for producing a silicon-on-insulator device according to one preferred embodiment of this invention.

#### DESCRIPTION OF THE PREFERRED EMBODIMENTS

[Para 22] Reference will now be made in detail to the present preferred embodiments of the invention, examples of which are illustrated in the

accompanying drawings. Wherever possible, the same reference numbers are used in the drawings and the description to refer to the same or like parts.

[Para 23] Fig. 1 is a circuit diagram of a silicon-on-insulator device according to one preferred embodiment of this invention. Fig. 2 is a structural diagram of a silicon-on-insulator device according to one preferred embodiment of this invention. As shown in Fig. 1, a silicon-on-insulator device 100 includes a transistor 102 and a control transistor 104. The transistor 102 further includes a drain terminal 106, a gate terminal 108 and a source terminal 110. The control transistor 104 further includes a source terminal 110, a gate terminal 112 and a drain terminal 114. Both the transistor 102 and the control transistor 104 use a common source terminal 110. The drain terminal 114 of the control transistor 104 and the main body of the transistor 102 are electrically connected.

[Para 24] The silicon-on-insulator device 100 is operated according to the following schemes. To switch the transistor 102 on, a bias voltage  $V_{cc}$  is applied to the drain terminal 106, a bias voltage  $V_{cc}$  is applied to the gate terminal 108 and 0V is applied to the source terminal 110 of the transistor 102. With this voltage setup, the main body of the transistor 102 and the source terminal 110 are electrically disconnected. The transistor 102 has a characteristic of floating-body silicon-on-insulator device and hence produces a higher opening current.

[Para 25] To switch the transistor 102 off, a bias voltage  $V_{cc}$  is applied to the drain terminal 106 of the transistor 102 and a 0V is applied to both the gate 108 and the source terminal 110 of the transistor 102. In the meantime, a bias voltage  $V_{cc}$  is applied to the gate terminal 112 of the control transistor 104. With this voltage setup, the main body of the transistor is electrically connected to the source terminal 110 through the conducting control transistor 104. Hence, the transistor 102 has a characteristic of non-floating body silicon-on-insulator device capable of reducing shut down current.

[Para 26] Fig. 2 is a top view of a silicon-on-insulator device according to one preferred embodiment of this invention. As shown in Fig. 2, the silicon-on-insulator device 200 includes an isolation structure 202, an active

region 204, a first conductive layer 206, a second conductive layer 208, a doped region 210, a first drain region 212, a source region 214, a second drain region 216, a conductive line 218, a first contact 202 and a second contact 222. The isolation structure 202 is disposed in the silicon-on-insulator substrate for isolating out the active region 204. The conductive layer 206 crosses over a portion of the active region 204 to serve as the gate structure 226 of the control transistor. The second conductive layer 208 crosses over a portion of the active region 204 to serve as the gate structure 226 of the control transistor. The doped region 210 is disposed inside the active region 204 to connect electrically with the main body of the transistor. The doping type of the doped region 210 is identical to the substrate. The drain region 212 is disposed in the active region 204 on one side of the gate structure 224. The source region 214 is disposed in the active region 204 between the first gate structure 224 and the second gate structure 226. In other words, the transistor and the control transistor share the same source terminal region 214. The drain region 212 is disposed in the active region 204 on another side of the gate structure 224. The doping type of the first drain region 212, the source region 214 and the second drain region 216 is opposite to the substrate. If the substrate is a P-type substrate, the first drain region 212, the source region 214 and the second drain region 216 are N-doped layers. On the other hand, if the substrate is an N-type substrate, the first drain region 212, the source region 214 and the second drain region 216 are P-doped layers. The conductive line 218 connects the drain region 216 and the doped region 210 of the control transistor through the first contact 220 and the second contact 222 respectively. In other words, the conductive line 218 connects the drain region 216 of the control transistor and the main body of the transistor.

[Para 27] Figs. 3A to 3E are schematic top views showing the steps for producing a silicon-on-insulator device according to one preferred embodiment of this invention. Figs. 4A to 4E are schematic cross-sectional views showing the steps for producing a silicon-on-insulator device according to one preferred embodiment of this invention. In fact, area A and area B in

Figs. 4A to 4E are respective cross-sectional views along line A-A' and B-B' of Figs. 3A to 3E.

[Para 28] As shown in Figs. 3A and 4A, a substrate 200 such as a P-type substrate is provided. A buried insulation layer 302 is formed in the substrate 300. The buried insulation layer 302 is formed, for example, using a separation by implanted oxygen (SIMOX) process or a bonded wafer process or a dielectric isolation (DI) method. The buried insulation layer 302 can be an oxide layer, for example.

[Para 29] An isolation structure 304 is formed over the substrate to mark out an active region 306. The isolation structure 304 is a field oxide layer such as a silicon oxide layer formed, for example, by local oxidation. Obviously, the isolation structure 304 can also be a shallow trench isolation (STI) structure, for example.

[Para 30] Thereafter, a gate dielectric layer 308 is formed over the substrate 300. The gate dielectric layer 308 can be a silicon oxide layer formed, for example, by thermal oxidation. A conductive layer 310 is formed over the substrate 300. The conductive layer 310 is a polysilicon layer formed, for example, by chemical vapor deposition.

[Para 31] As shown in Figs. 3B and 4B, the conductive layer 310 and the gate dielectric layer 308 are patterned using photographic and etching techniques so that the conductive layer 310 is patterned into a first conductive layer 312 and a second conductive layer 314. The first conductive layer 312 crosses over a portion of the active region 306 to serve as a gate structure for the transistor 316. Similarly, the second conductive layer 314 crosses over a portion of the active region 306 to serve as a gate structure for the control transistor 318. Thereafter, a patterned photoresist layer 320 is formed over the substrate 300. The patterned photoresist layer 320 covers the areas destined to form the doped regions. The doped region and the main body of the transistor 316 are in electrical contact. Using the patterned photoresist layer 320, the first conductive layer 312 and the second conductive layer 314 as a mask, an ion implant step 322 is carried out to form a first drain region 324, a source region 326 and a second drain region 328 in the substrate 300



on each side of the first conductive layer 312 and the second conductive layer 314. The dopants implanted into the substrate 300 in ion implant step 322 have a doping type that differs from the substrate 300 such as N-type phosphorus or arsenic ions. Both the transistor 316 and the control transistor 318 use the same source region 326.

[Para 32] As shown in Figs. 3C and 4C, the patterned photoresist layer 320 is removed and then another patterned photoresist layer 330 is formed over the substrate 300. The patterned photoresist layer 330 exposes the area for forming a doped region 334. Using the patterned photoresist layer 330 as a mask, an ion implant step 332 is carried out to form the doped region 334 in the substrate 300. The doped region 334 and the main body of the transistor 316 are in electrical contact. The dopants implanted into the substrate 300 in ion implant step 332 have a doping type identical to substrate 300 such as P-type boron ions.

[Para 33] As shown in Figs. 3D and 4D, the patterned photoresist layer 330 is removed and then an inter-layer dielectric layer 336 is formed over the substrate 300. The inter-layer dielectric layer 336 is made from borophosphosilicate glass (BPSG) or phosphosilicate glass (PSG) layer in a chemical vapor deposition, for example. Thereafter, a chemical-mechanical polishing operation is conducted to planarize the upper surface of the inter-layer dielectric layer 336. A first contact opening 338 and a second contact opening 340 are formed in the inter-layer-dielectric layer 336. The first contact opening 338 exposes a portion of the doped region 334 and the second contact opening 338 exposes a portion of the drain region 328.

[Para 34] As shown in Figs. 3E and 4E, conductive material is deposited to fill the first contact opening 338 and the second contact opening 340 so that a first contact 342 and a second contact 344 are formed inside the first opening 338 and the second opening 340 respectively. The first contact 342 and the second contact 344 are made from tungsten, for example. Thereafter, a conductive line 346 is formed over the inter-layer dielectric layer 336. The conductive layer 346 connects the first contact 342 with the second contact 344 electrically. In other words, the drain terminal 328 of the control

transistor 318 is electrically connected to the main body of the transistor 316. The conductive line 346 is formed, for example, by forming a conductive layer (not shown) over the inter-layer dielectric layer 336 and then carrying out photolithographic and etching processes. Finally, conventional steps for completing the fabrication of a complete silicon-on-insulator device are carried out. Since these steps are familiar to those skilled in the art of manufacturing, detailed description is omitted here.

[Para 35] According to the embodiment of this invention, a control transistor is disposed between the source terminal of a silicon-on-insulator device and a silicon main body. To switch on the silicon-on-insulator device, the control transistor is shut down. Since the main body of the silicon-on-insulator device is electrically disconnected from the source terminal, the silicon-on-insulator device has a characteristic of floating-body silicon-on-insulator device. Therefore, a higher opening current is obtained. To switch off the silicon-on-insulator device, the control transistor is turned on so that the main body of the silicon-on-insulator device connects electrically with the source terminal and the silicon-on-insulator device has a characteristic of non-floating body silicon-on-insulator device. Thus, a lower shutdown current is obtained. In this invention, through the set up of a control transistor between the source terminal of a silicon-on-insulator device and a silicon main body, the control transistor can be switched on or off on demand. Hence, the silicon-on-insulator device is able to embody the advantages of both the floating-body effect and body-tied characteristic and improve the reliability without compromising overall performance level.

[Para 36] It will be apparent to those skilled in the art that various modifications and variations can be made to the structure of the present invention without departing from the scope or spirit of the invention. In view of the foregoing, it is intended that the present invention cover modifications and variations of this invention provided they fall within the scope of the following claims and their equivalents.